Swift heavy ion induced radiation damage of $TmPO_4$*

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One of the key questions in ion-irradiation induced material degradation is why certain materials are easily damaged while others exhibit high radiation hardness. This work is part of a project investigating the response of lanthanide phosphates $LnPO_4$ to high electronic excitation. Using synthetic single crystals with lanthanide ions varying from Y, Sc, La, … up to Lu allows us to perform a systematic damage study. Depending on the lanthanide ion, the crystals are divided into two groups with similar structures. Crystals with the lanthanide ions of diameter larger that the one of Gd (Ln = La…Gd) form monoclinic ($P2_1/n$) crystal lattices, whereas the other phosphates (Ln = Y, Sc or Tb…Lu) form tetragonal ($I4_1/amd$) crystals. Here we present first results on $TmPO_4$.

The irradiation of $TmPO_4$ single crystals was performed at the UNILAC using 2.2 GeV Au ions. At this energy, the ion range is of the order of 80 µm. We applied fluences between 5×10^{10} and 5×10^{13} ions/cm^2 and a beam flux of either 10^8 or 10^9 ions/cm^{2}s. The irradiated crystals were analyzed by Raman spectroscopy using a Horiba LabRAM spectrometer with a laser of λ= 632 nm.

For radiation studies, an important information is the damage cross section which is directly related to the track radius. We thus analyzed the Raman spectra of crystals exposed to a fluence series (fig. 1) and deduced a track radius according to the Poison equation (single-impact model) assuming that each ion creates a cylindrical track:

$$A = A_0 \cdot \exp(-\pi r_{tr}^2 \Phi) \quad (1)$$

where r_{tr} is the track radius, Φ denotes the fluence, and A is the intensity ratio of the Raman bands at 1004 and 977 cm^{-1}. The band at 1004 cm^{-1} corresponds to symmetrical stretching of the PO_4 tetrahedron and is the most intense peak in Raman spectra of the virgin sample, whereas the 977 cm^{-1} band appears as a result of the irradiation. Figure 2 shows the evolution of the intensity ratio as a function of fluence. Fitting Eq.(1) to the data yields a track radius of 2.8±0.8 nm which is in agreement with track radii in other compound insulators such as $Y_3Fe_5O_{12}$ [1] or $NiFe_2O_4$ [2].

Figure 3 presents Raman spectra from irradiations with different fluence and flux parameters showing that the ion flux plays a significant role. For a fixed fluence, the spectrum from the irradiation with 10^8 ions/cm^{2}s shows higher degradation than under 10^9 ions/cm^{2}s (cf. black and red spectrum). At a flux increased by one order of magnitude twice as large a fluence is requires to provide the same amount of damage in the material (cf. blue and black spectrum).

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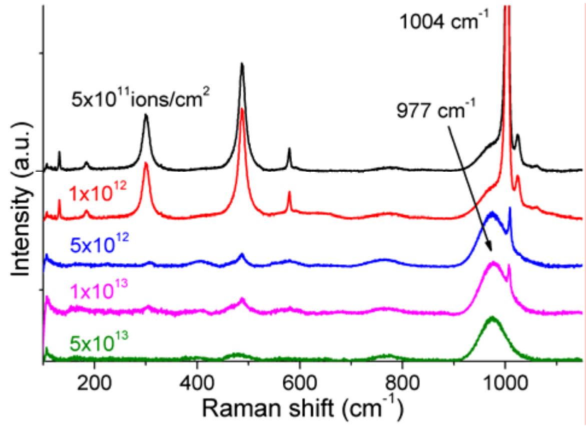

Figure 1: Raman spectra of $TmPO_4$ crystals exposed to 2.2-GeV Au ions. Damage creation increasing with fluence is indicated by significant broadening and intensity decrease of all bands.

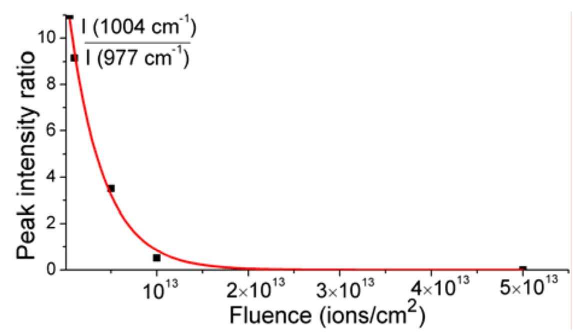

Figure 2: analysis of track radius fitting the ratio of 1004 to 977 cm^{-1} band intensities.

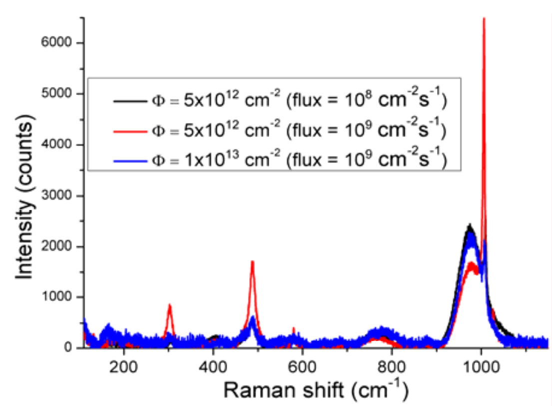

Figure 3: Raman spectra of $TmPO_4$ crystals irradiated at two different fluxes.

[1] A. Meftah et al., Phys. Rev. B 48 (1993) 920.
[2] M. Toulemonde et al., Sol. Stat. Phen. 30 (1993) 477.